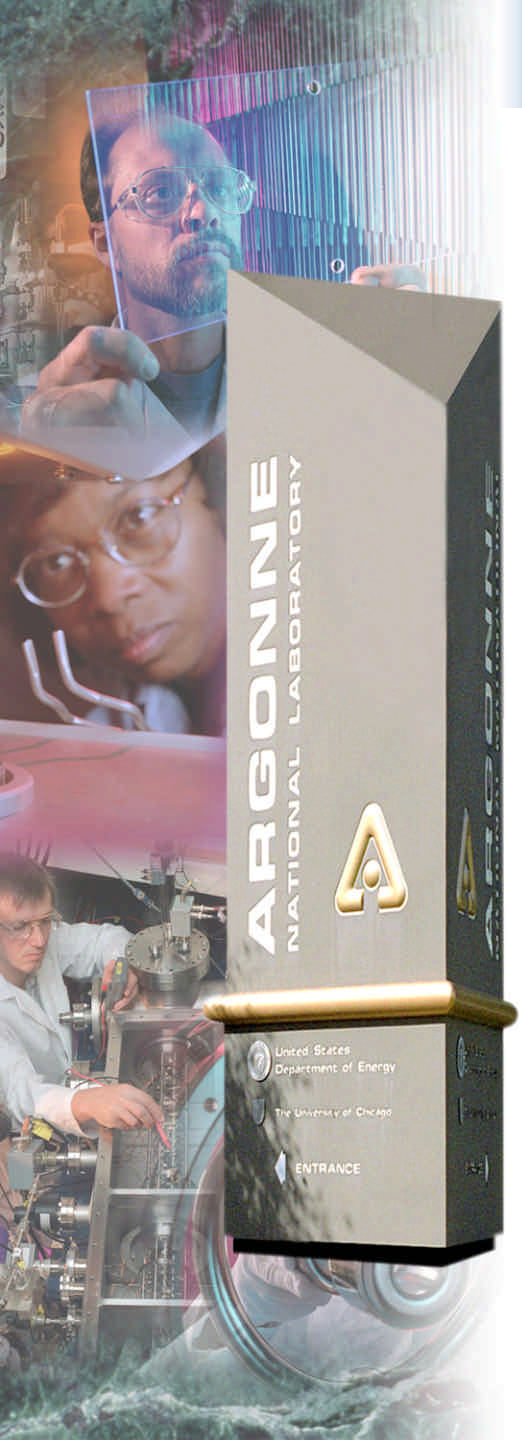
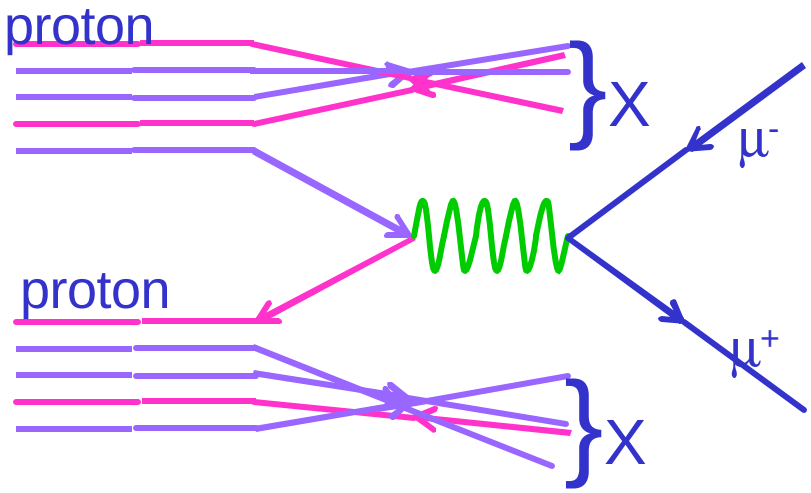


Opportunities with Drell-Yan scattering: Probing the sea quark distributions of the nucleon and nucleus

Paul E. Reimer

- *Using Drell-Yan to probe sea quark distributions*
- *What is the structure of the nucleon?*
  - Origins of the nucleonic sea: dbar/ubar in the proton
- *What is the structure of nucleonic matter?*
  - Nuclear pions and antishadowing of sea quarks
- *What are the properties of hot nuclear matter?*
  - Parton energy loss in cold nuclear matter
- *The E906 spectrometer*

Drell-Yan scattering (Fixed Target):
A laboratory for studying sea quark distributions

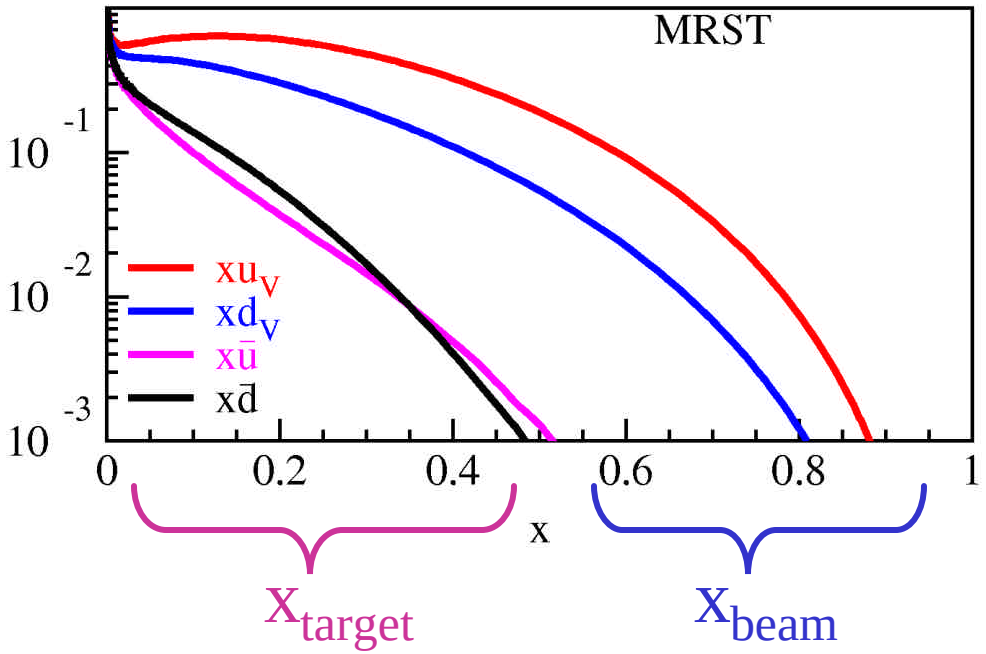


Leading Order

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\times \sum_i e_i^2 \left[\bar{q}_{ti}(x_t)q_{bi}(x_b) + q_{ti}(x_t)\bar{q}_{bi}(x_b)\right]$$

- Detector acceptance chooses range in x_{target} and x_{beam}.
- $x_F = x_{beam} - x_{target} > 0$
- high-x Valence *Beam* quarks.
- Low/interm.-x sea *Target* quarks.

$$x_F \approx 2p_L/\sqrt{s} = x_1 - x_2$$
$$M^2_{\mu^+\mu^-} = sx_1x_2$$



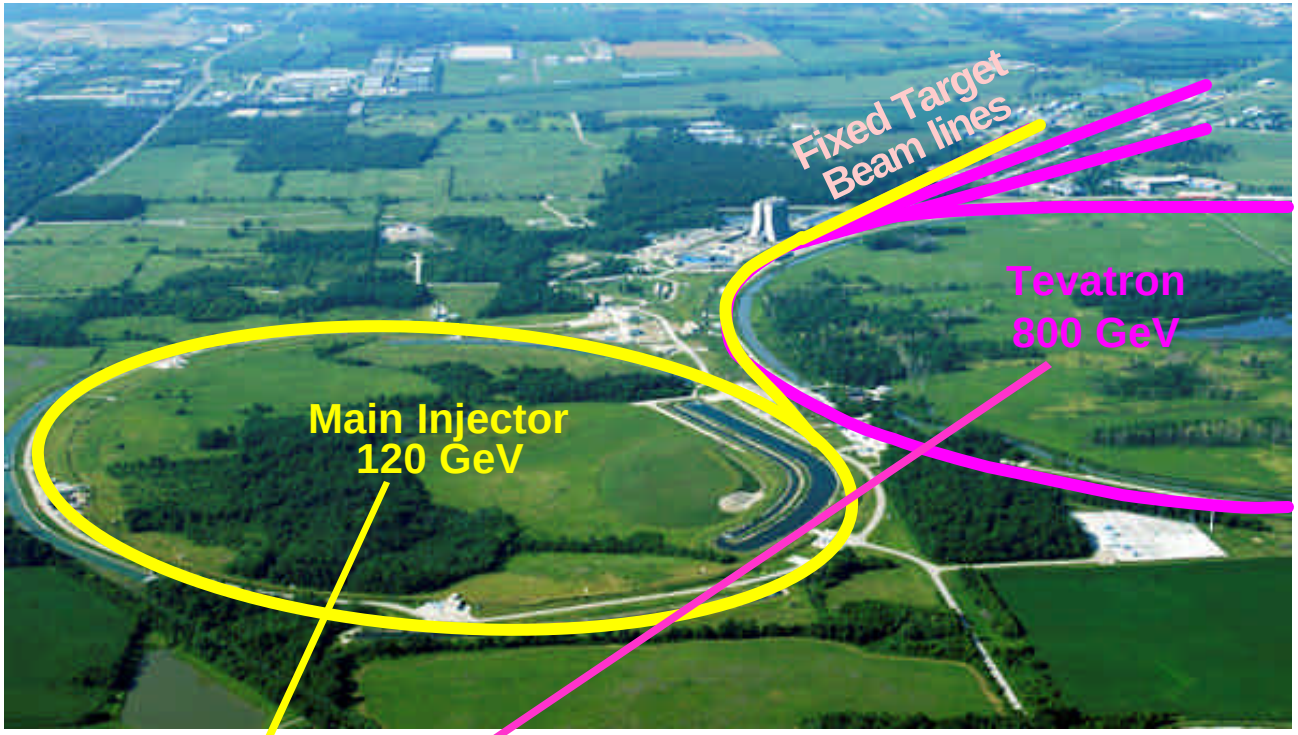
Fermilab Accelerator Complex: Fixed Target Program

E866 vs. E906:

800 vs. 120 GeV

- Cross section scales as 1/s
  - 7× *that of 800 GeV beam*
- Backgrounds (J/ψ decay) scale as s
  - 7× *Luminosity for same detector rate as 800 GeV beam*

50× statistics!!



$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s} \times \sum_i e_i^2 \left[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t)q_{bi}(x_b)\right]$$

FNAL E906 Collaboration

Abilene Christian University
Donald Isenhower, Mike Sadler, Rusty Towell

Argonne National Laboratory
John Arrington, Don Geesaman*, Kawtar Hafidi, Roy Holt, Hal Jackson, Paul E. Reimer*, David Potterveld

University of Colorado
Ed Kinney

Fermi National Accelerator Laboratory
Chuck Brown

University of Illinois
Jen-Chieh Peng

Los Alamos National Laboratory
Gerry Garvey, Mike Leitch, Pat McGaughey, Joel Moss

Rutgers University
Ron Gilman, Charles Glashausser, Xiaodong Jaing, Ron Ransome

Texas A & M University
Carl Gagliardi, Bob Tribble, Maxim Vasiliev

Thomas Jefferson National Accelerator Facility
Dave Gaskell

Valparaiso University
Don Koetke

*Co-Spokespersons

FNAL E866/NuSea Collaboration

Abilene Christian University
Donald Isenhower, Mike Sadler, Rusty Towell, Josh Bush, Josh Willis, Derek Wise

Argonne National Laboratory
Don Geesaman, Sheldon Kaufman, Naomi Makins, Bryon Mueller, Paul E. Reimer

Fermi National Accelerator Laboratory
Chuck Brown, Bill Cooper

Georgia State University
Gus Petitt, Xiao-chun He, Bill Lee

Illinois Institute of Technology
Dan Kaplan

Los Alamos National Laboratory
Melynda Brooks, Tom Carey, Gerry Garvey, Dave Lee, Mike Leitch, Pat McGaughey, Joel Moss, Brent Park, Jen-Chieh Peng, Andrea Palounek, Walt Sondheim, Neil Thompson

Louisiana State University
Paul Kirk, Ying-Chao Wang, Zhi-Fu Wang

New Mexico State University
Mike Beddo, **Ting Chang**, Gary Kyle, Vassilios Papavassiliou, J. Seldon, **Jason Webb**

Oak Ridge National Laboratory
Terry Awes, Paul Stankus, Glenn Young

Texas A & M University
Carl Gagliardi, Bob Tribble, **Eric Hawker**, Maxim Vasiliev

Valparaiso University
Don Koetke, Paul Nord

Structure of the nucleon: What is d-bar/u-bar in the proton? Why?

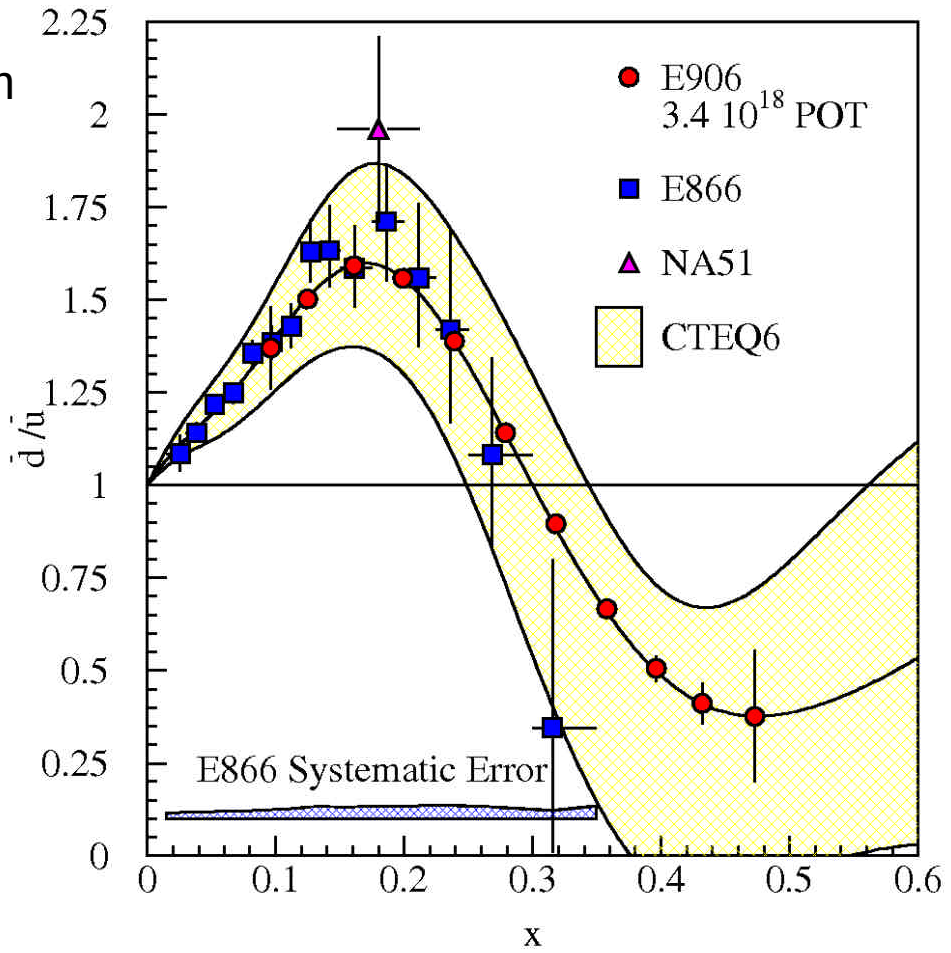
Parton Distributions

- Study ratio of cross sections for deuterium to hydrogen

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

(In analysis, we use a full Next-to-Leading order cross section calculation with both terms)

- PDF fits are and uncertainties completely dominated by E866.
- E906 will significantly extend these measurements and improve on uncertainty.



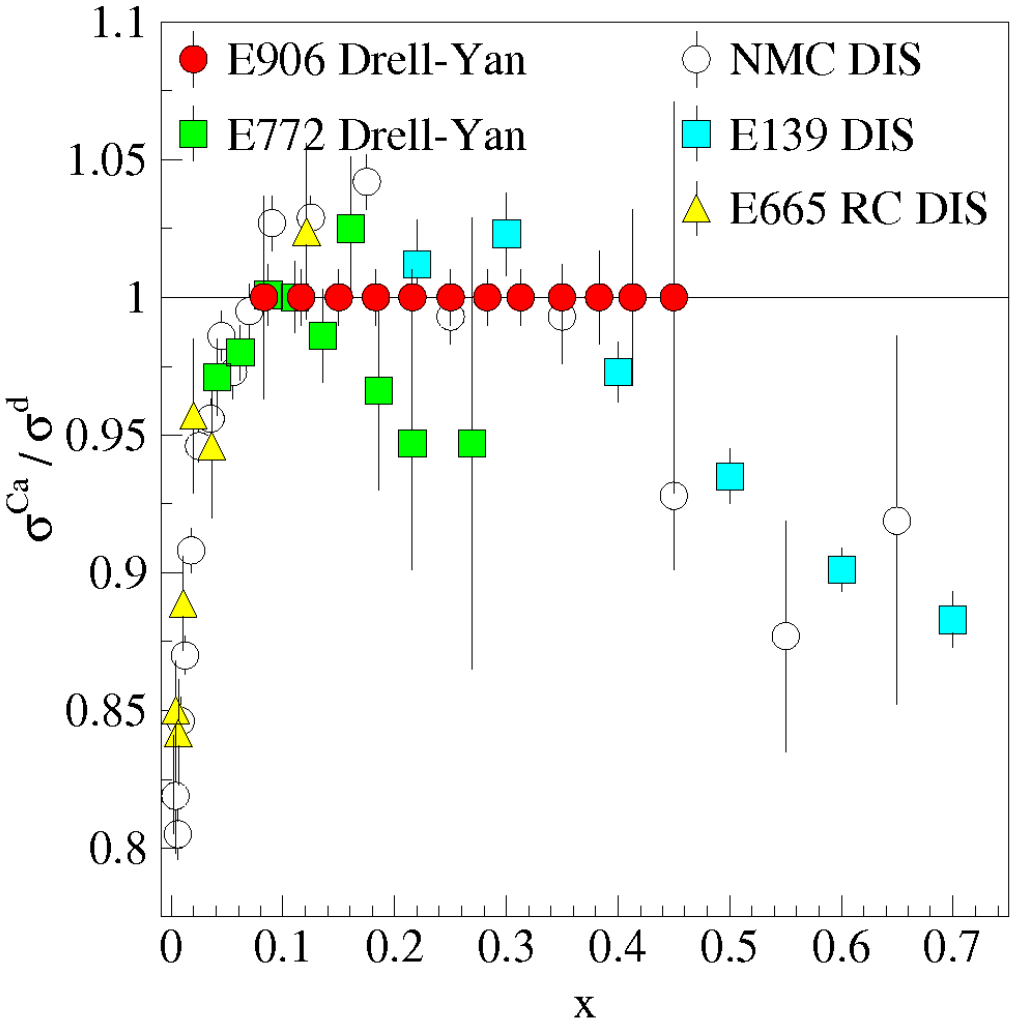
Impact

- Collider/LHC sensitivity for tests of the Standard Model—Background.
- Origins of the Proton Sea—Models explain d-bar $\geq$ u-bar. No theory (model) expects the results seen for x $\geq$ 0.3.

Structure of nucleonic matter: How do sea quark distributions differ in a nucleus?

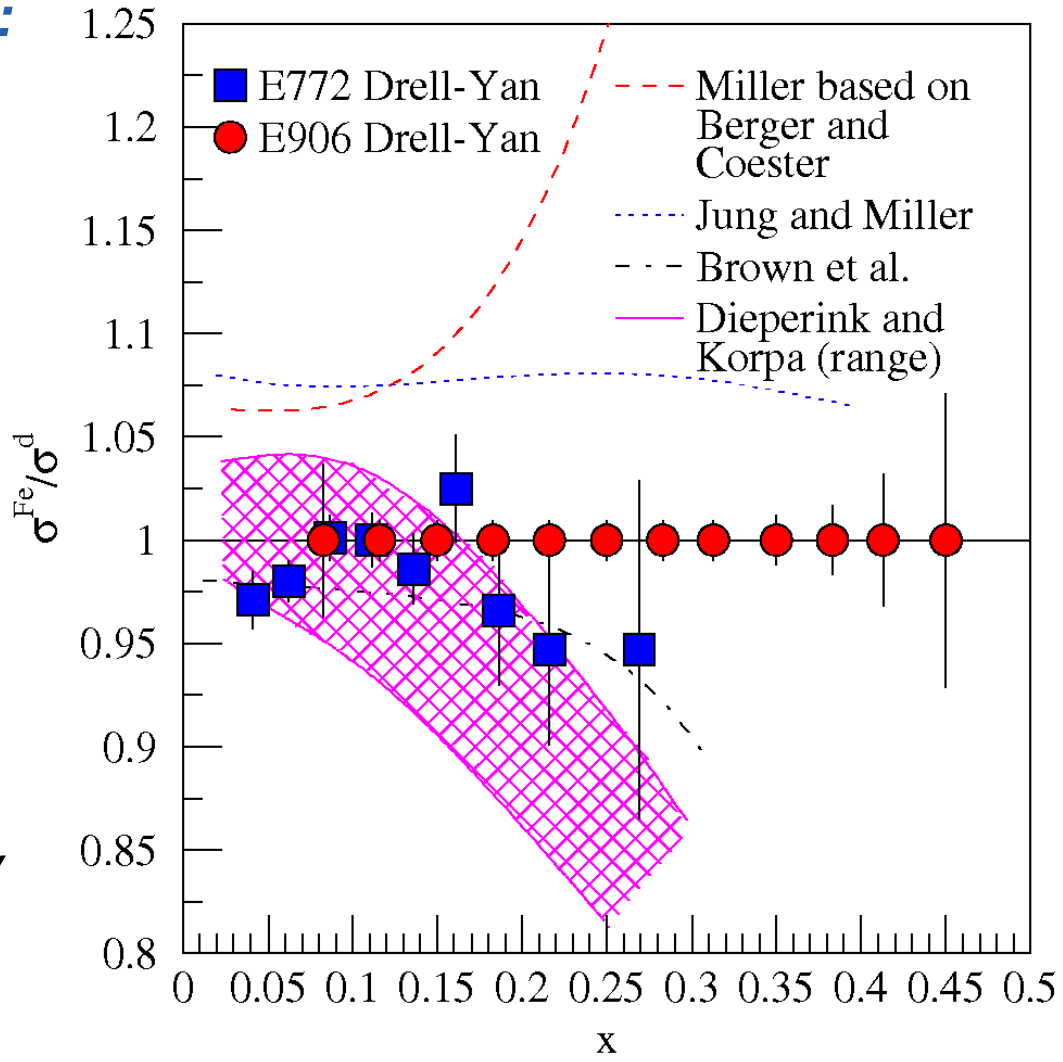
Comparison with Deep Inelastic Scattering (DIS)

- Antishadowing not seen in Drell-Yan—Valence only effect?—better statistical precision needed—E906.
- Intermediate-*x* *sea* PDF's set by ν-DIS on iron—unknown nuclear effects.
- What can the sea parton distributions tell us about nuclear binding?

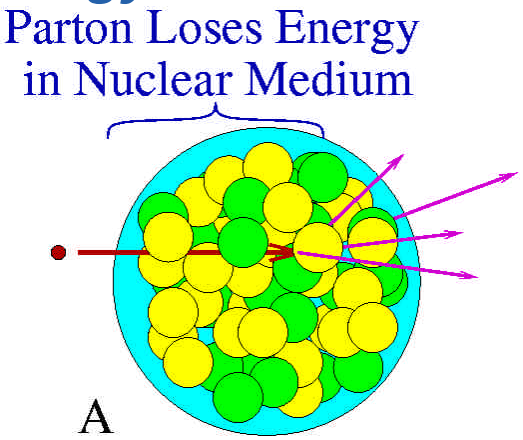


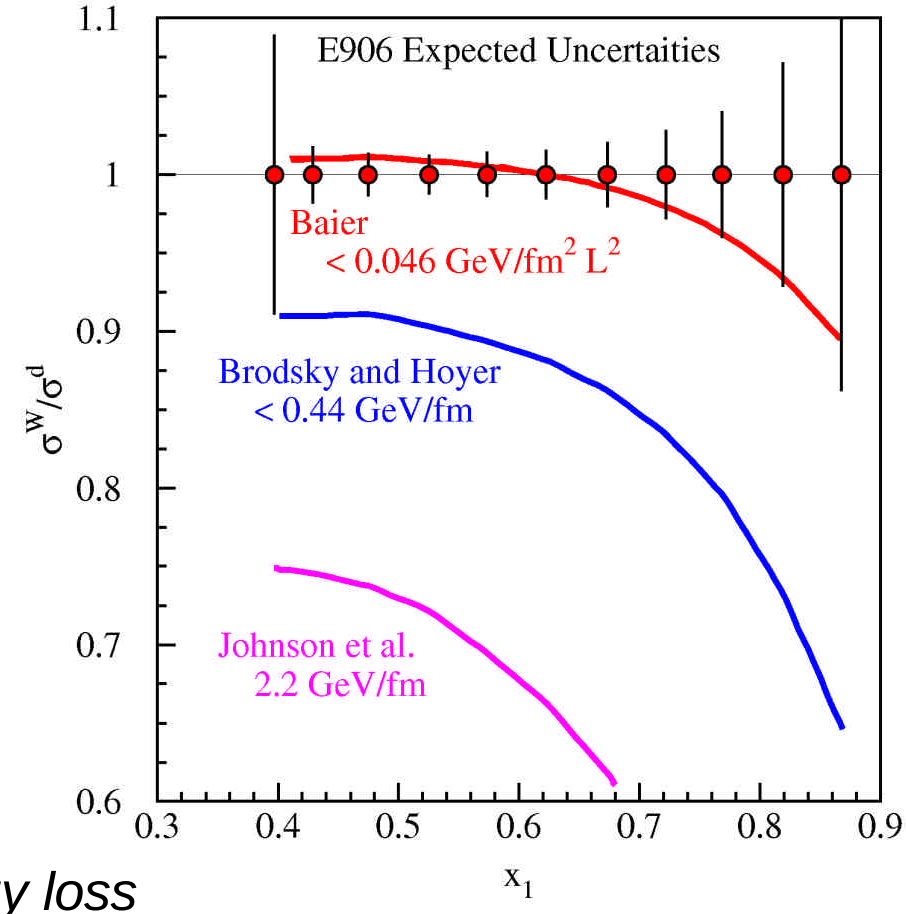
Structure of nucleonic matter: Where are the nuclear pions?

- The binding of nucleons in a nucleus is expected to be governed by the exchange of virtual “Nuclear” pions.
- Antiquark enhancement expected from Nuclear Pions.
- Early predictions (Berger and Coester) proved false by Fermilab E772 Drell-Yan data.
  - *Note that E772 has relatively large uncertainties, especially as x increases.*



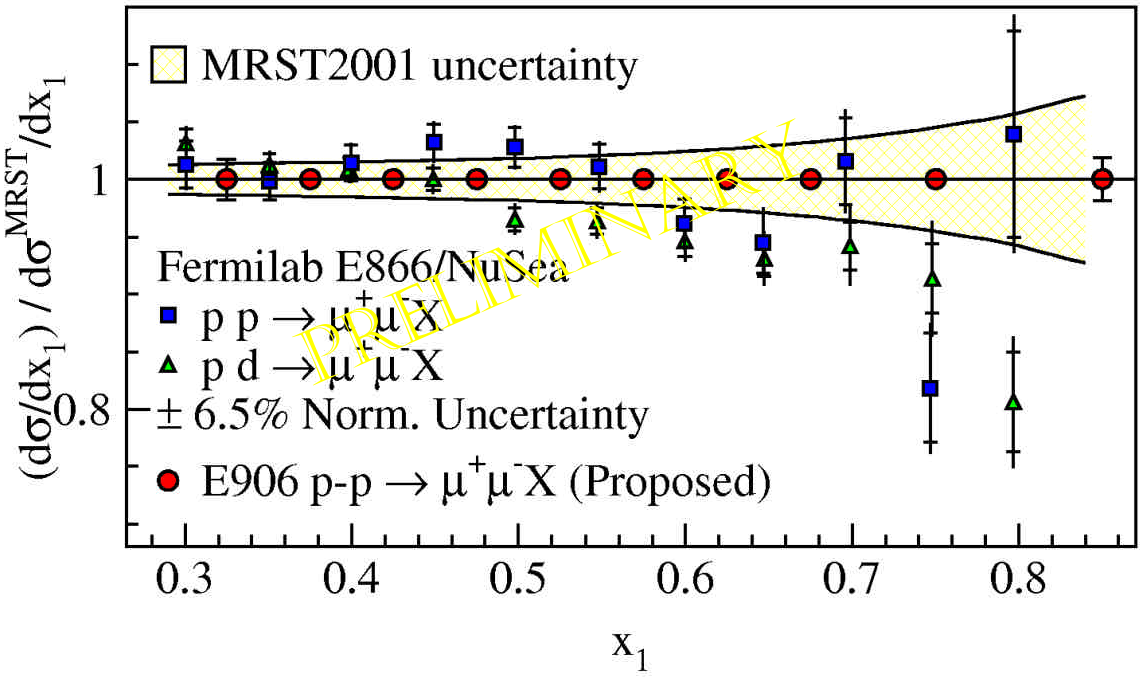
Parton Energy Loss





- Colored parton moving in strongly interacting media.
- Only initial state interactions are important—*no final state strong interactions*.
- *E866 data are consistent with no energy loss*
- Treatment of parton propagation length and shadowing are critical
  - Johnson *et al*. find 2.2 GeV/fm from the same data
- Energy loss $\propto$ 1/s—larger at 120 GeV
- Important to understand RHIC data.

Drell-Yan Absolute Cross Sections: Proton Structure as $x \to 1$



MRST and CTEQ: $d/u \to 0$ as $x \to 1$

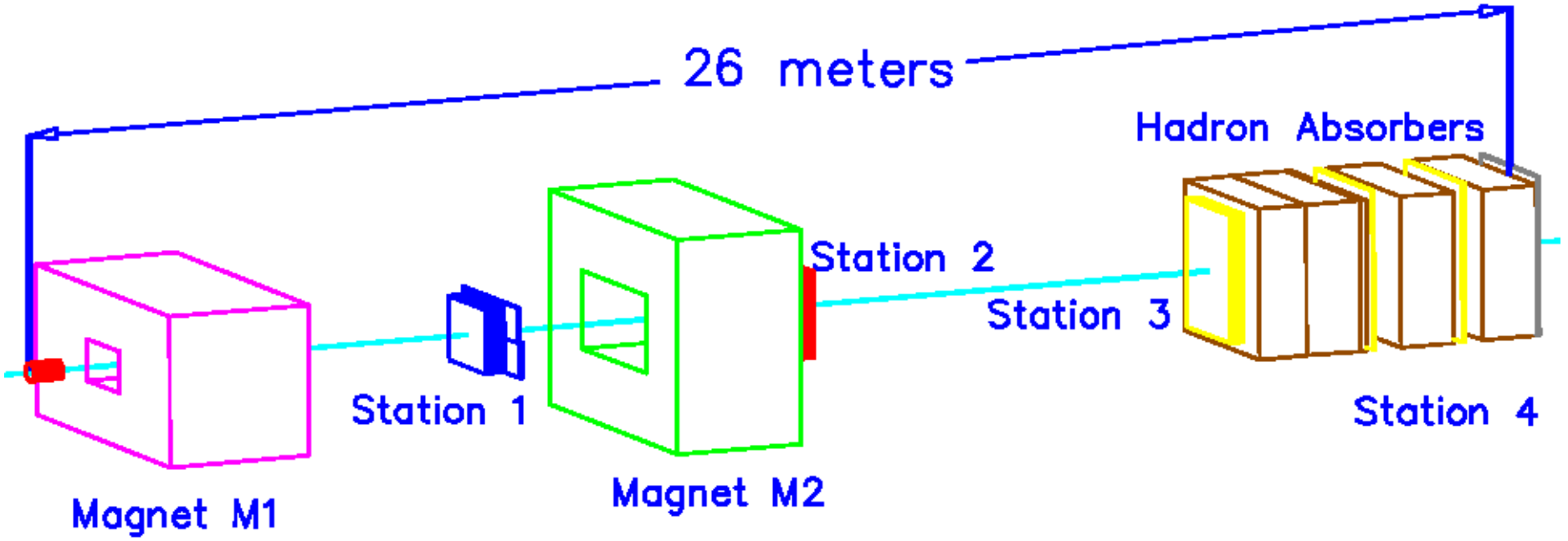
Radiative corrections calculations are now finished—small effect.

Fermilab E906 will add much more precise high-*x* data.

- Reach high-x through *beam proton*—Large xF)large xbeam.
- Proton-Proton—no nuclear corrections—*4u(x) + d(x)*
- Proton-deuterium (cross check) agrees with proton-proton data.
- Parton distributions overestimate cross section.
- Working with CTEQ to incorporate data in global PDF fits.

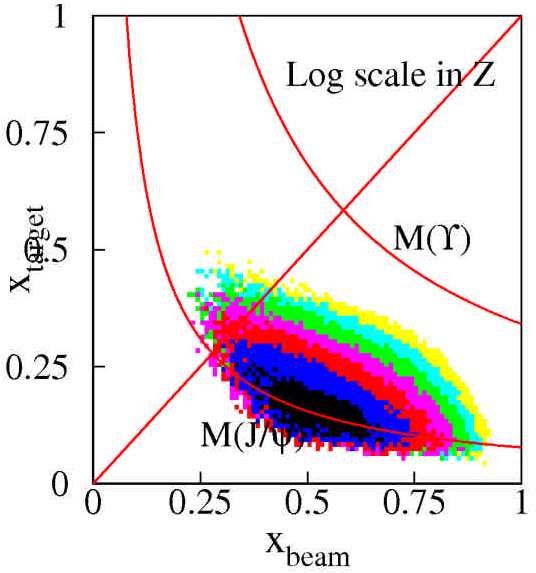
E906 Apparatus

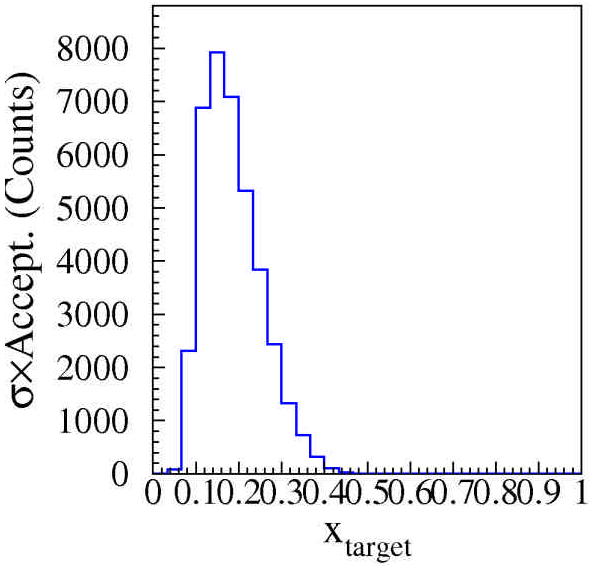
- **Boost difference between 800 and 120 GeV requires shorter experiment.**
  - Previous (E866) spectrometer was over 60m long; E906 spect. is only 26m long
  - Fabrication of new coils for M1 magnet (was 14.5 m long new M1 is only 4.8 m)
  - Complications with π decays between target and absorber
- **Other items:**
  - New Station 1 to handle higher rate
  - Replace some *very old* scintillators, additional phototubes
- **Key to rates: Beam dump and hadron absorber within M1 Magnet**

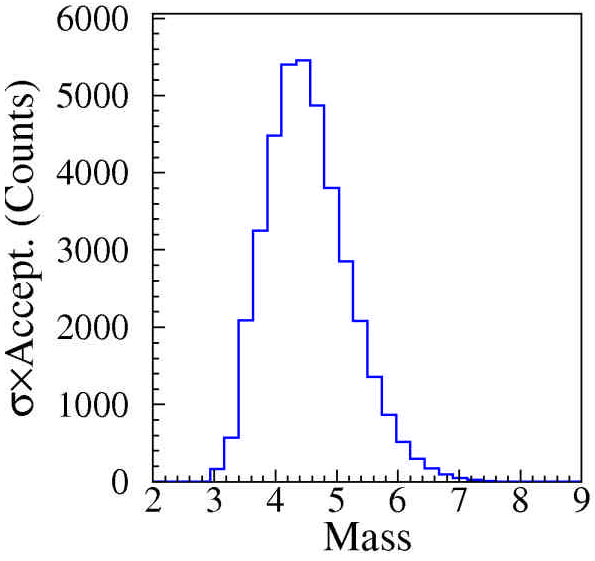


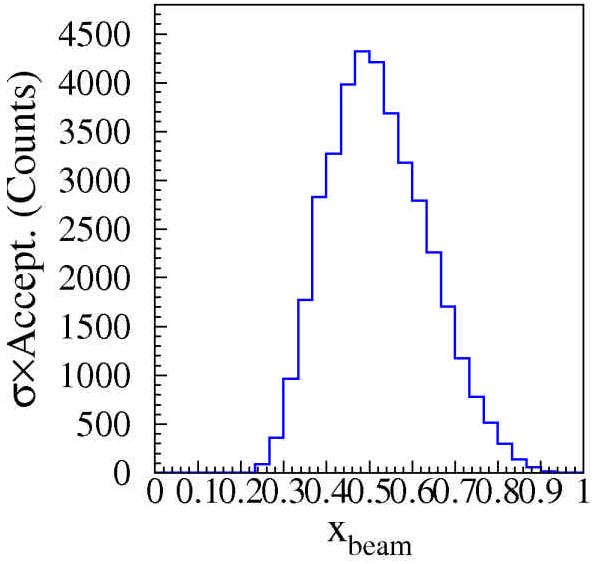
Drell-Yan Acceptance

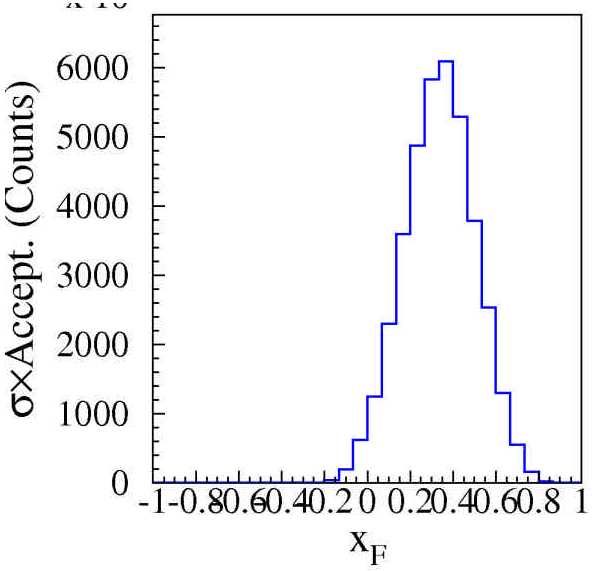
- Programmable trigger removes likely J/ψ events
- Transverse momentum acceptance to above 2 GeV
- Spectrometer could also be used for J/ψ, ψ′ studies





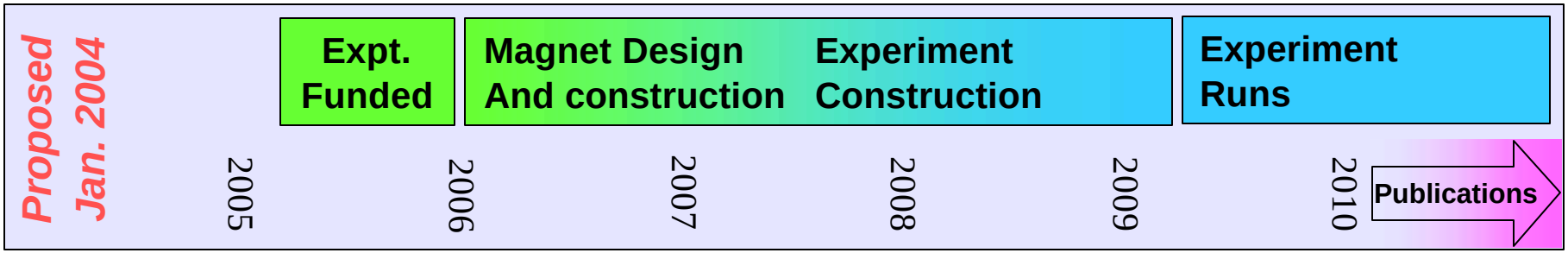






E906 Cost and Schedule

- **Fermilab Long Range Schedule—Committed to starting E906 in FY2009**
  - Must have minimal impact on instantaneous neutrino production.
  - Require slow extraction out of Main Injector.
- **Approximate Cost:**
  - Magnet coil fabrication: US$1.4M
  - US$0.8M for Spectrometer upgrades
- **Funding sources**
  - US DOE-Office of Nuclear Physics US$2.0M
  - US NSF US$0.3M
  - Fermilab support through magnet assembly, electronics, power supplies, *etc*



Drell-Yan at Fermilab

- **Fixed-Target Drell-Yan is the ideal way to study the quark sea.**
- **What is the structure of the nucleon?**
  - –d-bar/u-bar at intermediate-*x*
  - –Parton distributions as x→1
- **What is the structure of nucleonic matter?**
  - –Where are the nuclear pions?
  - –Is antishadowing a valence effect?
- **Do partons lose energy?**
- **Answers from Fermilab Drell-Yan**
  - –Significant increase in physics reach
  - –Scheduled to run in 2009